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GB 2172766 A WO 86/07513 A US 3694656 A

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(54) **Optical phase-diversity receivers**

(57) A phase-diversity receiver for a coherent optical communication system comprises polarisation control means (11 to 14) acting on a received optical signal (1) and an optical local oscillator signal (2) to ensure that those signals are elliptically polarised and are in phase quadrature. The elliptically polarised signals are combined in a coupler (15) whose outputs (c,d) are then split (at 16 and 17) into four output signals which, upon detection, provide photocurrents at relative phases 0°, 180°, 90° and 270°. Local oscillator noise is eliminated by combining the 0° and the 180° outputs, and by combining the 90° and 270° outputs.

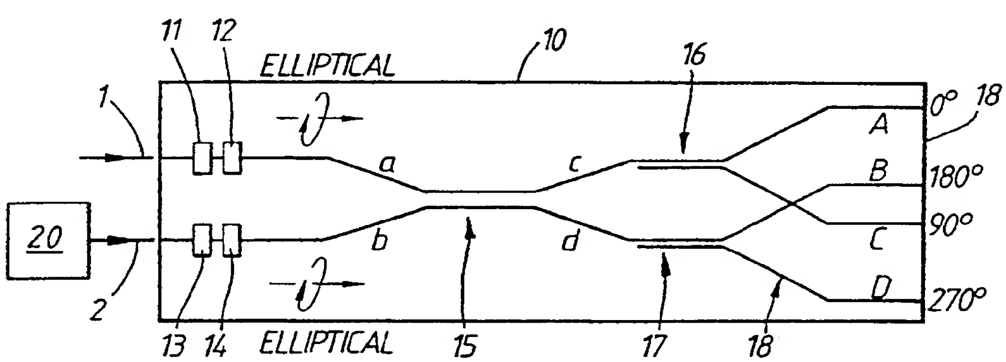

FIG. 2.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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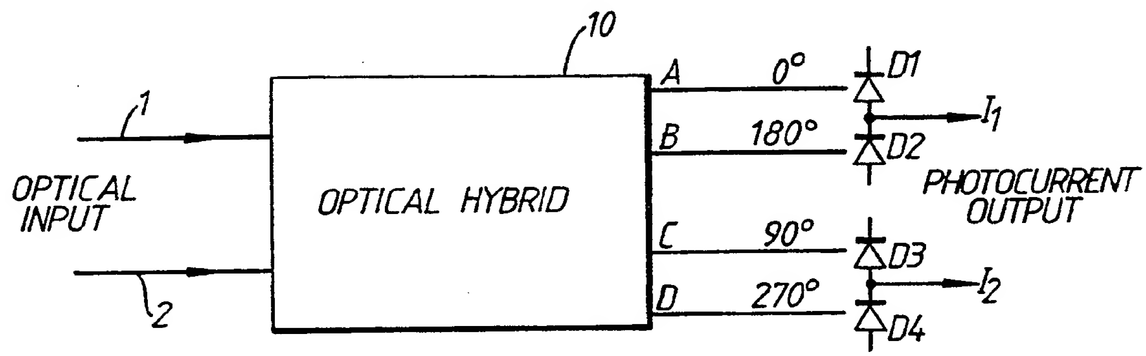

FIG.1.

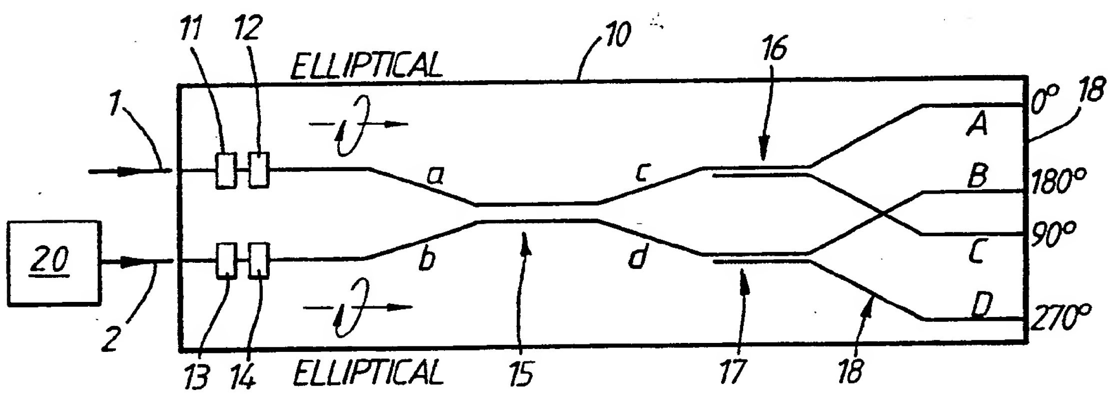

FIG.2.

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Optical Phase-Diversity Receiver

This invention relates to a phase-diversity receiver for a coherent optical communications system.

Two problems which face designers of heterodyne and coherent optical systems are those of matching the polarisation and phase of the received signal with the local oscillator signal. Polarisation matching is necessary in any heterodyne scheme, and both phase and polarisation need to be matched for the higher performance coherent schemes. The problems arise since the two quantities vary randomly at the far end of an optical fibre. Furthermore, if more than one optical signal is frequency-multiplexed onto the same fibre, the phase and polarisation states of each source are in general uncorrelated. Thus, if a receiver is required to switch between frequency channels, a rapid means of matching and tracking the received signal with the local oscillator signal is needed.

Two known solutions to these problems are active compensation and diversity reception. In the case of active compensation, a control loop applies phase compensation between the two inputs to the receiver according to the state of the electrical output signals. Such a method has the advantage of optimally matching the input signals and thus achieves maximum efficiency.

However, the control algorithms may be fairly complex, and thus the response time to sudden changes is likely to be slow.

In the case of diversity reception, two separate circuits detect orthogonal states, for example in-phase and quadrature components, and recombine these signals electrically before thresholding. In this way, the receiver is made insensitive to random fluctuations without the need for a feedback loop, and is therefore very fast. The penalty paid in a diversity scheme is a small reduction in sensitivity, from that obtained with an active compensation scheme. It has been proposed to use the phenomenon of polarisation in an optical receiver to achieve phase-diversity reception. The purpose of the present invention is to provide such a receiver which may readily be implemented in an integrated optical device.

Accordingly, the invention provides a phase-diversity receiver for a coherent optical communications system, comprising an optical local oscillator, polarisation control means for acting on a received optical signal and/or the optical local oscillator signal to ensure that those signals are elliptically polarised and are in phase quadrature with each other, and a polarisation-diversity processing unit for combining the elliptically-polarised signals and for splitting the combined signals into two orthogonal polarisation states such that, on detection, the resulting electrical output signals are in phase

quadrature with each other, at least the polarisation control means and the polarisation-diversity processing unit being formed as an integrated optical device.

Preferably, the polarisation-diversity processing unit splits the said combined signals into four polarisation states such that there are four output signals with relative phases 0°, 90°, 180° and 270°. This allows local oscillator intensity noise to be virtually eliminated, by combining electrically the outputs of opto-electric detectors for the 0° and 180° output signals, and similarly combining the detector outputs of the 90° and 270° output signals, in a balanced detection configuration.

One way in which the invention may be performed will now be described, by way of example only, with reference to the accompanying drawing, in which:

Figure 1 is a diagram of a phase-diversity homodyne receiver embodying the invention and

Figure 2 is a more detailed diagram, still in schematic form, of an integrated optical device forming part of the receiver of Figure 1.

With reference first to Figure 1, an optical circuit 10 has for its optical input a received signal 1 and a signal 2 from a local oscillator laser 20. In this example, for homodyne reception, the two optical inputs are at the same frequency. The received signal may be of

any arbitrary polarisation, whereas the local oscillator signal should have a polarisation which is known, but need not necessarily be linear. Four outputs A, B, C and D are provided with respective phases 0°, 180°, 90° and 270°, to respective opto-electric detectors D1, D2, D3 and D4. The receiver has a balanced detection configuration for the virtual elimination of local oscillator intensity noise: the intermediate frequency photocurrents generated in detectors D1 and D2 are combined, as are those in detectors D3 and D4, to provide respective orthogonal photocurrent outputs I1 and I2.

With reference now to Figure 2, the optical circuit 10 is formed as an integrated optical device on an X-cut or Y-cut, Z-propagating lithium niobate substrate. The optical input is provided by optical fibres which interface with corresponding waveguide channels on the circuit 10. The four opto-electric detectors D1 to D4 are butt-coupled directly onto the end face 18 of the circuit 10, so that each detector is coupled to its respective one of four output waveguide channels in the circuit 10.

The circuit 10 comprises polarisation control elements 11, 12, 13 and 14, in series with a polarisation-diversity processing unit comprising elements 15, 16 and 17. Polarisation control for the received signal 1 is provided by a phase shifter 11 in series with a mode converter 12. Polarisation control for the local oscillator signal 2 is provided by an oppositely arranged

pair, namely a mode converter 13 and a phase shifter 14. The signals emerging from the polarisation control elements have known elliptical polarisation states which are 90° out of phase with each other.

The elliptically-polarised signals at a and b are combined in a polarisation-independent coupler 15 whose outputs c and d, at equal power, are supplied respectively to TE/TM polarisation splitters 16 and 17. The two outputs A and C of one polarisation splitter 16 provide signal outputs at relative phases 0° and 90° respectively, whereas the outputs B and D of the other polarisation splitter 17 provide outputs at relative phases 180° and 270° respectively.

In this example, the output from the polarisation splitters 16 and 17 reach the end face 18 of the circuit 10 by way of a cross-over network 18 of waveguide channels, and are thus provided directly to the butt-coupled detectors D1 to D4, but alternative arrangements are of course possible, for example configurations involving optical fibres.

The degree of integration could be extended by arranging that the opto-electric detectors and/or the local oscillator laser are integrated with the other elements of the receiver, using a semi-conductor material system such as indium phosphide.

The use of only two polarisation control elements 11,

12 (13, 14) in each signal arm is advantageous since it minimises power loss. With present technology it is possible to limit the optical power loss for the signal to 1.1dB, caused by a 0.2dB total interface loss (Fresnel and modal mismatch losses), a 0.5dB loss in the two polarisation control elements, a 0.2dB loss in the coupler 15 and splitter 16, 17 elements, and a 0.2dB excess loss due to imperfect splitting and other imperfections. For balanced detection, the power split between outputs A and B (C and D) must be equal, to a high degree of accuracy: a one percent imbalance would provide a 20dB local oscillator noise rejection, and a 0.1 percent imbalance would allow a 30dB local oscillator noise rejection. In the example described, equal splitting to within about 2 percent is presently possible, leading to a 14dB local oscillator noise rejection.

The invention may also be embodied in a low intermediate frequency heterodyne receiver, for which separate in-phase and quadrature inputs would be required to provide the necessary phase information.

CLAIMS

1. A phase-diversity receiver for a coherent optical communications system, comprising an optical local oscillator, polarisation control means for acting on a received optical signal and/or the optical local oscillator signal to ensure that those signals are elliptically polarised and are in phase quadrature with each other, and a polarisation-diversity processing unit for combining the elliptically-polarised signals and for splitting the combined signals into two orthogonal polarisation states such that, on detection, the resulting electrical output signals are in phase quadrature with each other, at least the polarisation control means and the polarisation-diversity processing unit being formed as an integrated optical device.

2. A receiver according to claim 1, wherein the polarisation control means comprise a mode converter in series with a phase shifter processing the received optical signal to give it a predetermined elliptical polarisation, and a mode converter in series with a phase shifter for processing the local oscillator signal to give it a different pre-determined elliptical polarisation.

3. A receiver according to any preceding claim, wherein the polarisation diversity processing unit comprises a polarisation-independent coupler for combining the elliptically-polarised signals and at least one polarisation splitter for receiving an output of the

polarisation-independent coupler and producing the said output signals.

4. A receiver according to any preceding claim, wherein the polarisation-diversity processing unit splits the said combined signals into four polarisation states such that there are four output signals with relative phases 0°, 90°, 180° and 270°.

5. A receiver according to claim 4, comprising an opto-electric detector arranged to detect each of the output signals, and means for combining the detector outputs of the output signals with relative phases 0° and 180°, and for combining the detector outputs of the output signals with relative phases 90° and 270°, for balanced detection such that local oscillator noise is rejected.

6. A receiver according to any of claims 1 to 4, comprising an opto-electric detector for detecting each of the output signals.

7. A receiver according to claim 5 or 6, wherein each opto-electric detector is butt-coupled directly onto an end face of the device.

8. A receiver according to any preceding claim, wherein the integrated optical device comprises an X-cut or Y-cut, Z-propagating substrate.

9. A receiver according to claim 8, wherein the substrate is of lithium niobate.

10. A receiver according to any preceding claim, wherein

the local oscillator signal has a known polarisation, and the received signal has an arbitrary polarisation.

11. A receiver according to any preceding claim, adapted for homodyne reception with optical inputs at the same frequency.

12. A receiver according to any of claims 1 to 10 adapted for low intermediate frequency reception, comprising means for receiving in-phase and quadrature components of the received signal.

13. A phase-diversity receiver substantially as described herein with reference to the accompanying drawings.

14. A method of homodyne reception, substantially as described herein with reference to the accompanying drawings.

15. A method of heterodyne reception, substantially as described herein with reference to the accompanying drawings.

16. A phase-diversity receiver for a coherent optical communications system, comprising an optical local oscillator and a polarization-diversity optical receiver arranged to combine a received optical signal with a signal from the optical local oscillator to produce a combined output signal of which two orthogonal polarization states are capable of producing, on detection, electrical signals which are in phase quadrature, the said receiver comprising polarization control means for ensuring that the received optical

signal and the local oscillator signal are in phase quadrature when they are so combined.

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